OVERCOMING ACCESS ISSUES AT A REMOTE PASSIVE TREATMENT SITE NEAR LAKE SHASTA, CA [1]

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Abstract. Constructing bench scale and pilot scale sulfate reducing bioreactors (SRBRs) at abandoned mine sites can become routine until the site is accessible only by boat. The Golinsky site is a small underground copper mine complex consisting of abandoned mine workings and remnants of smelter operations located on a steep hillside above Little Backbone Creek, a tributary to Lake Shasta. The mine pool (impounded behind bulkheads) is typical acid rock drainage with a pH of 2.5 to 4 containing heavy metals including iron, aluminum, copper, zinc, cadmium, and manganese. The US Forest Service committed to a bench and pilot scale testing program to demonstrate that the SRBR technology would work at the remote site and reduce metal loading on Lake Shasta. However, accessing the site requires a three-mile boat trip across the lake and a two-mile hike along a narrow abandoned railroad grade from the beach head to the mine. The windows of construction access were controlled by the weather but also by changing lake levels. Bench and pilot SRBR test systems were constructed in 2004.

For the pilot system, all the materials (about 45 tons) and construction equipment were hauled across Lake Shasta in a WWII vintage landing craft. Efficiently off-loading this quantity of material was a challenge that was met with an innovative cable tramway system strung between the landing craft and a shore-based tower consisting of two large pine trees. Implementing the amphibious "assault" on "D-Day" with just one landing craft was complicated enough; indeed, the experience invoked a greater respect for the Allied soldiers and commanders in Normandy almost 60 years to the day earlier.

Additional Keywords: acid rock drainage, heavy metals, sulfate reducing bioreactors acid mine drainage

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Introduction

The Golinsky Mine is an abandoned underground base metal mine near Lake Shasta, located in Shasta County, California in the Shasta-Trinity National Forest (see Figure 1). The mine was last active in the early part of the 20th century (SHN, 2004) when copper and zinc and minor amounts of the precious metals were recovered. The mine and an associated milling/smelting complex are in rugged, mountainous terrain. While active, the mine was accessible by a narrow gauge railway that hugged the steep hillside above Little Backbone Creek. The mine was reportedly closed in 1937 when the site's accessibility was severely restricted as a result of the construction of a nearby dam on the Sacramento River (Kinkel et al., 1956). The rising water in the reservoir effectively isolated the mine site from the outside world by flooding the narrow gauge railway alignment. While the rails and ties were removed, an occasional tie and railroad spike can still be found. A part of the site is occupied by an abandoned limestone quarry that serviced a smelter whose site was also submerged by the rising reservoir.

Today, the site can only be reached by boat, about a three-mile (4.8 km) trip from either of two boat launch sites. The mine complex is about a two-mile (3.2 km) hike from the landing site in Little Backbone Bay. The mine complex is at an elevation of 1800 ft. (549 m); the shoreline of Lake Shasta is at an elevation of about 980 ft. (300 m).

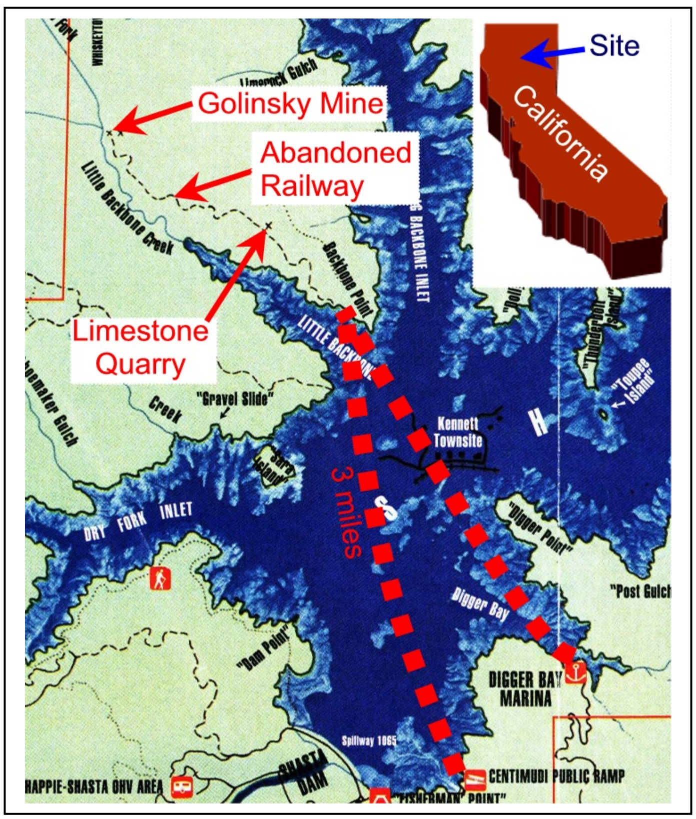

Figure 1. Site vicinity

The geochemistry of the Golinsky Mine ore was dominated by sulfide mineralization, including pyrite. This condition lead to the inevitable production of acid rock drainage (ARD) from three adits, two of which now have concrete bulkheads that prevent surface water discharge with the exception of minor seepage in the spring season when the main mine pool behind the bulkheads is full. The third adit discharges ARD that fails to meet water quality standards, more so in the spring. In this situation, it is hypothesized that contaminated mine pool water is mixing with the otherwise clean water that may have discharged historically from the third adit prior to the bulkheads' construction. The mine pool chemistry has a pH of 2.5 to 4 and contains heavy metals including iron, aluminum, copper, zinc, cadmium, and manganese.

In late 2003, Region 5 of the U.S.D.A. Forest Service elected to investigate methods of treating and discharging the Golinsky Mine pool water (behind the bulkheads) and collect and treat the ARD discharging from the third adit. These measures would help to protect Little Backbone Creek, which is a tributary to Lake Shasta. Due to the site's inaccessability and total lack of infrastructure; i.e., no power, passive treatment methods were viewed as especially attractive.

The primary purpose of this paper is to provide information on the access challenges at this remote site and how they were overcome. The final results of the ongoing tests at the site will be addressed in a future paper; however, preliminary results are provided.

Phased Treatability Study

A two-phased treatability study was commissioned to determine if sulfate reducing bioreactors (SRBRs) were an appropriate technology for passively treating the mine pool ARD. Experience had shown that ARD with chemistry much more aggressive than the Golinsky Mine's could be passively treated with an SRBR (Gusek and Schueck, 2004). However, as there is no standard organic substrate mixture for SRBRs due to the variability of components, a bench scale study was implemented as the first phase to determine the best "recipe" among four "best-bet" mixtures.

Bench Scale Test

There were two potential locations for the bench scale test:

- Off-site, at a rented storage area or at nearby Forest Service facilities, or
- At the mine site where ARD could be easily collected on a continuous basis.

Both locations would require periodic site visits but a completely different level of logistical effort.

For the off-site option, a large amount of ARD would require handling. Under continuous operation, each 55-gallon capacity (200 liter) bench scale test cell would require about 12.5 to 16 liters of ARD per day. Thus, a week's worth of flow for four cells would require up to about 120 gallons (450 liters). Transporting this volume of ARD down 3.2 km of narrow hiking path and across the lake on a weekly schedule was not deemed feasible.

To locate the bench test cells at the mine required a reliable method of delivering up to 16 liters of ARD to each cell per day. This flow rate equates to about 11.1 milliliters per minute, or about a drip or two per second. Previous experience with off-the-shelf drip irrigation tubing and needle valves was less than desirable: ferric hydroxide precipitates tend to clog narrow tubing and nearly daily maintenance is required to insure the proper amount of ARD is being delivered.

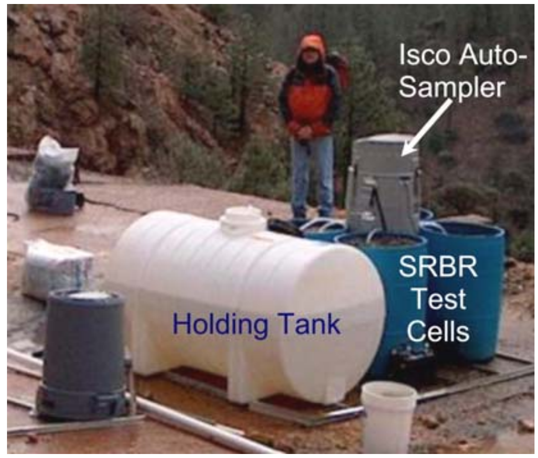

Figure 2. Bench test cell setup

Multiple battery-powered automatic samplers were used effectively in delivering periodic slugs of ARD to five bench test cells at a remote forest site in Pennsylvania (Gusek and Wildeman, 2002). For the Golinsky Mine project application, an Isco ™ Model 6712 automatic sampler was modified and deployed as follows:

- four one-gallon (3.8 liter) sample bottles were fitted with drain tubing,
- four holes were drilled (on the four compass points) in the bottom portion of the auto-sampler to allow the drain tubing to exit the sampler's waterproof housing,
- the auto sampler was positioned above and equidistant from the four SRBR bench scale test cells (see Figure 2), and
- the autosampler was programmed to deliver a slug of about four liters of ARD from a 350-gallon holding tank to each test cell every six hours (four slug deliveries per day).

In the above scenario, the site would require visitation every week to sample the test cells and to refill the holding tank with fresh ARD from one of the bulkheaded portals. Experience showed that the 12-volt deep-cycle marine battery that powered the autosampler would need to be exchanged with a recharged fresh unit every two weeks. If weather or other circumstances prevented site access, the system could function for up to about three weeks before the holding tank ran dry or the battery was completely discharged. No provisions were made to automatically collect samples; in this circumstance, the sampling events were skipped.

Constructing the bench test system was completed in two stages. Once the construction materials were collected, the bench cells were assembled off-site at a USFS maintenance facility that was adjacent to the lake. This took about a full day of effort. The following day, the cells were temporarily dismantled and all the necessary materials and equipment were loaded on to a rented barge as shown on Figure 3.

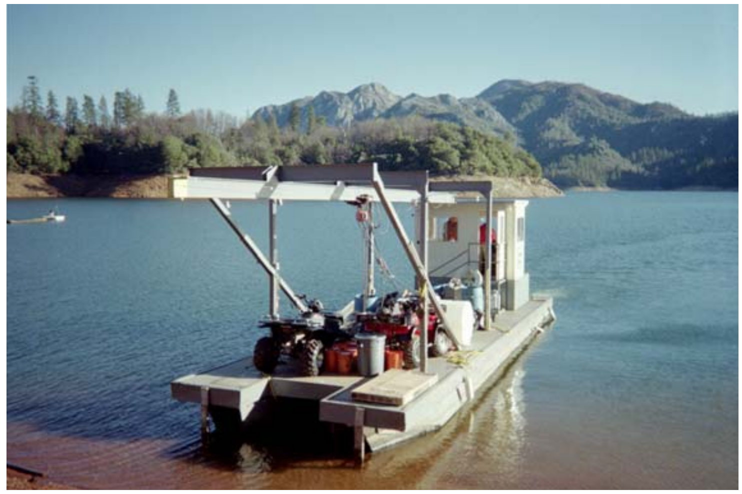

Figure 3. Barge loaded with bench test materials and equipment

Moving the material and equipment from the beach head to the mine site was complicated by a major snow storm about a week before the field effort began in late-January, 2004. The storm knocked trees and rocks on to the narrow access road; it took a full day of chain saw and access clearing by hand just to reach the mine site. In subsequent visits, a sheet metal garden shed was constructed over the test cells to provide protection from the elements. While freezing might have been an issue at other remote sites, it was not a problem at the Golinsky Mine. The site experienced snowfall events, but hard freezes were infrequent. If freezing became a problem, insulation would have been used to surround the cells and holding tank, and solar-oriented methods would have been used to keep the bench cell temperatures from dropping too low.

The results of the bench scale test showed that nearly all the organic substrate recipes behaved about the same with regard to metal removal and pH improvement. Thus, the final mixture (number 3) was primarily selected based on economics tempered with the “jump start” that was apparently provided by the rice hulls. Table 1 below provides the proportions used in the four bench cells with the recipe selected for the pilot cell shaded.

Table 1. Bench SRBR cell recipes

Component	Cell 1	Cell 2	Cell 3	Cell 4
Ash	1 %	1 %	1 %	1 %
Co-Gen Fuel	50 %	16.5 %	40 %	25 %
Limestone Chips	29 %	29 %	29 %	29 %
Hay	10 %	10 %	10 %	10 %
Rice Hulls	0 %	33.5 %	10.0 %	25 %
Cow Manure	10 %	10 %	10 %	10 %
Totals	100 %	100 %	100 %	100 %

Pilot Scale Test

Similar to the bench scale test, there were two potential locations for the pilot scale test:

- At the mine site where ARD could be easily collected and fed to the pilot cell on a continuous basis, or
- At the Limestone Quarry site, approximate 1.5 miles (2.3 km) away.

The level of logistical effort required to construct the pilot scale SRBR cell was several orders of magnitude greater than that required to build the bench cells. For the pilot system, about 43 short tons (39,000 kg) of organic substrate comprised of wood chips, crushed limestone, rice hulls, hay, and cow manure needed to be delivered to the pilot scale site along with other construction materials.

If the pilot system was constructed at the mine, the substrate would need to be hauled the full distance from the “beach head”, along a narrow one-lane access road. If the pilot system was built at the limestone quarry site, the next logical flat piece of land large enough to accommodate the 32- foot by 32-foot square pilot cell (9.8 m x 9.8 m), a 1.5 mile (2.4 km) long pipeline system would need to be built to deliver the ARD on a continuous basis. Fortunately, the mine was about 286 feet (87 m) higher than the quarry site; a gravity flow pipeline would be feasible.

The quarry site also offered easier access for sampling events and it was considered the obvious site for the full-scale system if the pilot SRBR cell performed as well as the bench test cells. The logistics of transporting the substrate materials across Lake Shasta was daunting enough; negotiating the narrow access road to the mine was the most influential factor supporting the decision to locate the pilot SRBR cell at the quarry site.

The uncertainty of soil conditions at the quarry site precluded the construction of the pilot SRBR cell using earthen berms and a plastic liner which is standard practice. Similar to construction used in a similar situation at an abandoned copper mine site in Wyoming (Reisinger and Gusek, 1998), the rigid walls of the pilot cell were prefabricated off-site using plywood and construction lumber materials. This approach facilitated the construction process; the only major earthwork required at the quarry site would be the leveling of the SRBR cell footprint and the erection of the cell walls took less than a day.

There were two obvious alternatives for cross-lake transport of the construction materials:

- helicopter, and
- barge.

The economics of helicopter transport were not favorable; safe load limits would require 120 hours of flight time at about US$500 per hour for a total cost of about US$60,000, subject to weather conditions. Fortunately, a local resort, Lake Shasta Caverns, maintained a World War II vintage landing craft (LC) that was available for private rental at the bargain rate of US$75 per hour (operator included) plus fuel. The capacity of the LC was 14 short tons (12,730 kg). Theoretically, the substrate material could be transported across the lake in about three 4-hour trips plus mobilization/demobilization time. The LC would also be used to transport the construction equipment (a small trackhoe, 4x4 pickup truck, two all-terrain vehicles) and other construction materials (prefabricated plywood panels that would comprise the walls of the pilot SRBR test cells, liners, and pipes). Helicopter transport of the equipment and material would not have been feasible in any case. The total estimated cost of using the LC was about US$17,500. While the hourly rate of the LC subsequently increased to US$125 per hour, it was still more economical than a helicopter.

Figure 4. “Elsie” the landing craft from Shasta Lake Caverns

Figure 5. Highline in use

Off-Loading the Landing Craft Challenge

Regardless of whether a helicopter or landing craft were to be used for material transport, all loose materials such as the organic substrate needed to be containerized for ease of handling. The 43 tons of substrate presented a volume of about 120 cubic yards (92 cubic meters). One cubic yard capacity open-top woven polypropylene fabric “Supersacks” were utilized for the organic substrate. At about 800 pounds (364 kg) each, they could be easily handled with light-duty equipment (front end loader or trackhoe).

The landing zone at the "beach head" on the project-side of the lake, however, was quite steep (3H:1V). Off-loading the supersacks directly on to the bed of a 4x4 pickup truck was not feasible – even with a single supersack, the truck would have a difficult time climbing out of the beach head area. Originally, a tugger-hoist/winch arrangement was envisioned to facilitate the rapid unloading of the LC and positioning the supersacks a short distance up the beach head slope to allow their transfer to the 4x4 pickup bed. The pickup would then transport the supersacks (two at a time) the one mile from the beach head to the quarry site. This concept was to basically drag the supersacks up the steep beach head slope.

Co-author D. Lindsay proposed an innovative alternative to the tugger-hoist winch concept: a "highline", or aerial tramway would be strung between the LC and a shore-side tower. In operation, the supersacks would be fully-suspended on their journey from the LC to a staging area about 40 vertical feet (12 m) up the slope. The highline would consist of the following major components (see Figures 5 and 6):

- a load-bearing steel cable/fixed trolley line,
- a shore-side tower (comprised of two mature pine trees, well guyed),
- an LC based tower (welded steel construction),
- a traveling pulley-block with a chain hoist, and
- a bridle-tension line attached to the traveling pulley.

The bridle-tension line would pass through another pulley (anchored to the shore-side tower) and be attached to the 4x4 pickup truck which would provide the muscle to pull the supersacks from the LC to the top of highline. One drawback to the concept was that the highline system would need to be re-strung and dismantled for each LC trip. However, with only four trips envisioned, this was not enough of a deterrent to abandon the concept.

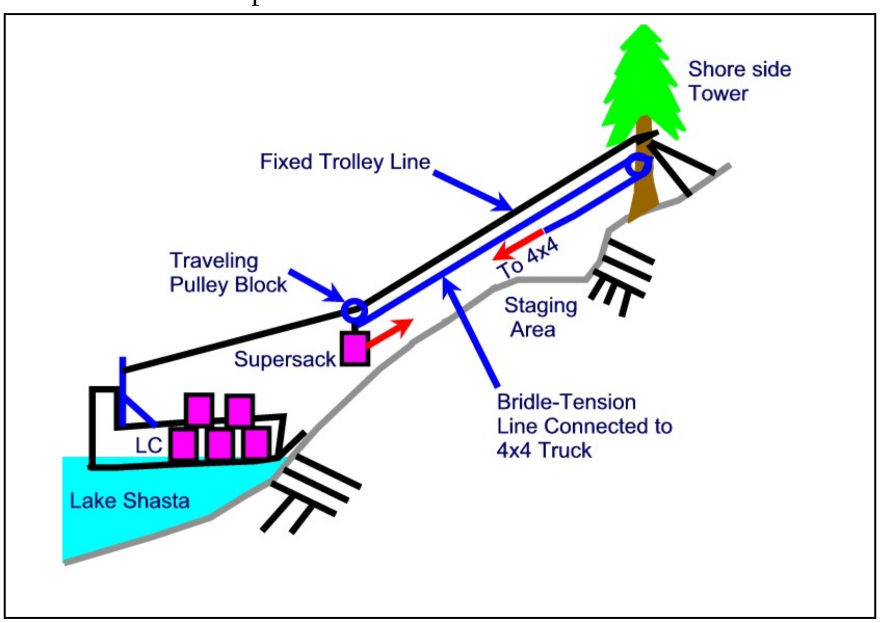

Figure 6. Sketch of highline

While there were several instances of highline system problems which were quickly solved, it was quite a safe and efficient method of off-loading the LC. Setup of the highline system typically took about an hour and the cycle time for off-loading a single supersack was about five minutes. At the top of the highline system, the supersacks dragged on the ground for about 15 feet (5 m), but the polypropylene fabric was quite tear resistant; not a single supersack load was broken in the transport effort despite the occasional mistreatment.

In retrospect, the highline system offered additional flexibility not originally envisioned at the project outset. The timing of the material and equipment mobilization across the lake was significantly influenced by lake pool elevations. The pilot cell construction was scheduled for the spring of 2004, when lake levels were the highest. This ideal situation would allow the shortest configuration for the fixed trolley line. Once the spring runoff began declining and the reservoir levels dropped (at about a foot [250 mm] per day) due to hydroelectric required releases, the configuration of the highline system was extended as needed.

Delivery Pipeline Challenges

Delivering about one gpm (3.84 liter/m) of ARD from one bulkheaded mine adit to the pilot SRBR cell (see Figure 7) by gravity offered some significant project challenges as well. To economize, off-the-shelf HDPE pipe typically used in domestic sprinkler systems was the pipeline material of choice. However, the availability of suitable size and strength pipe in the Redding, California metropolitan area and vicinity was somewhat restricted. Under static pressure loading conditions, the elevation drop of 286 feet (87 m) between the mine portals and the pilot cell would generate pressures that would exceed the bursting strength of the readily available pipe. As the pipe would not be completely buried along its 8,000 linear feet (2.4 km) length, solar heating would further reduce the burst strength. The solution adopted was the insertion of a pressure break/head tank into the pipeline system at the mine site. The elevation difference would then be in the acceptable range to avoid pipe bursting if the flow was stopped or throttled at the quarry site.

Figure 7. Finished SRBR pilot test cell

Engineering calculations that assume ideal conditions and field reality sometimes do not agree. The installed pipeline profile had many places where air-lock conditions prevailed. In order to develop sufficient pressure to overcome these multiple restrictions, the intermediate head tank was removed from the system and an operational policy that precluded throttling flow at the pilot cell was adopted. Flow throttling was accomplished at the mine portal site.

The initial performance results of the pilot system were quite favorable; over 99 percent removal of heavy metal loading with a circum-neutral discharge pH were achieved within about a month after startup in July, 2004. In November, 2004, the small scale pipeline delivery system was replaced with a buried 6-inch (150 mm) diameter HDPE pipeline that will service the full-scale passive treatment system to be constructed at a future date. In the five months that the small scale delivery pipeline was used (July to November, 2004), the only maintenance problem of consequence was damage from local wildlife. Inquisitive black bears bit into the exposed pipe, leaving small punctures that required occasional repair.

The construction of the 6-inch pipeline offered its own challenges. When helicopter transport of about 8,000 linear feet (2,440 m) of pipe proved to cumbersome and too time-consuming, the project team took advantage of the natural buoyancy of HDPE pipe. The pipe was floated across the lake in bundled "rafts" resembling "log jam" transport of harvested timber as shown in Figure 8.

Figure 8. Transport of 6-inch HDPE pipe across Lake Shasta

Preliminary Results

The pilot SRBR cell has been operating since July, 2004 and will be decommissioned in October 2006. The analytical results provided in Table 2 are average dissolved concentrations from October 2004 (post-startup) through July 2006 from thirty-two sampling events.

Table 2. Preliminary pilot SRBR cell results as of July, 2006 -

Parameter	**Influent**	**Effluent**	**30 meters downstream of SRBR Effluent**
pH range (s.u.)	2.1 – 4.2	6.4 – 7.8	7.4 – 8.4
Iron (mg/L)	60	8.0	1.7
Aluminum (mg/L)	22	0.098	0.088
Manganese (mg/L)	0.70	1.7	1.1
Zinc (mg/L)	31.7	1.4	0.70
Copper (mg/L)	12	0.021	0.033
Nickel (mg/L)	0.024	0.0074	0.0057
Cadmium (mg/L)	0.40	0.0047	0.0034
Sulfate (mg/L)	603	463	394
Flow (gpm)	1.0		

The preliminary results above suggest that with adequate polishing, an SRBR system effluent would probably meet drinking water standards.

Adjusting the feed flow rate became problematic in early 2005; the analytical results from a February sampling event (Table 3) reflect the pilot system's response to overloading from a flow rate that was twice the design rate. Due to a coincidental deterioration in mine water chemistry, the net result was the metal mass overload of three times the design value. This condition prevailed for about a month. Temporary overloading might be expected in a full-scale system, so this situation was viewed with caution and considered more of an opportunity to observe the system's response to "real-world" conditions. It is noteworthy that the average analytical results listed in Table 2 include the overloading event. Once the load was reduced to the design rate, it took approximately a month for the pilot system to return to pre-overloading conditions. In the full-scale design, flow overloads will be diverted around the primary treatment units and the by-passed flow will be mixed with the treated flow. This overloading event management policy should protect the primary treatment units.

Because of the excess alkalinity concentrations typically observed in SRBR effluents, the mixing of the system effluent and the by-passed flow should also provide a measure of treatment above and beyond that expected from dilution alone.

Table 3. Preliminary pilot SRBR cell results – February, 2005

Parameter	Influent Water Dissolved Conc.	Effluent Water Dissolved Conc.	30 meters downstream of SRBR Effluent
pH (s.u.)	2.6	6.6	7.5
Iron (mg/L)	162	22	7.9
Aluminum (mg/L)	44.2	0.035	<0.03
Manganese (mg/L)	0.85	4.3	4.1
Zinc (mg/L)	47.2	5.0	2.5
Copper (mg/L)	33.3	<0.005	<0.005
Nickel (mg/L)	0.044	0.008	0.007
Cadmium (mg/L)	0.47	0.005	0.004
Sulfate (mg/L)	1104	1,089	1,104
Flow (gpm)	2.0 (results in 3X metal mass overloading)		

The unintentional overloading of the pilot cell revealed that the removal of copper, the primary contaminant of concern, was virtually unaffected. However, the quality of the effluent deteriorated with respect to other parameters. As previously discussed, this situation abated about a month after the flow to the system was corrected to an appropriate level, demonstrating the resiliency of the SRBR passive treatment process.

Closing Remarks

There were numerous safety issues confronting the project team: remoteness of the activity (sometimes out of cellular telephone range), heat stress from elevated summer temperatures (over 100ºF/38ºC), and the multiple water crossings (sometimes in foul weather). Thankfully, the project was completed without incident. The delivery of supersacks commenced on June 15, 2004, coincidentally almost 60 years to the day of a historical amphibious landing in France. The complexities of the Golinsky Mine pilot SRBR system construction pale in comparison to that monumental effort of which the authors now have a much greater appreciation. Regardless, the authors hope that our collective experiences at this challenging site will benefit other engineers and scientists confronting similar site access issues.

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